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An airline maintenance manpower planning model with flexible strategies

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Abstract

An effective maintenance manpower supply plan not only reduces operating costs but ensures greater aviation safety and punctuality. A variety of flexible management strategies have been widely applied in other industries; however, little research has stressed flexible management strategies for airline crew scheduling problems. Here, we introduce a model that includes various flexible strategies so that an airline can effectively manage its maintenance manpower supply. The model is formulated as a mixed integer program that is solved using a commercial software package, CPLEX. In order to evaluate the model performance, we use the operating data from a leading Taiwan airline.

Keywords: Maintenance manpower supply; Crew scheduling; Flexible management strategy; Mixed integer program

1. Introduction

Effective aircraft maintenance plans cannot only reduce operating costs, but are also directly related to improving flight safety. A maintenance schedule that meets all the safety requirements will also help to ensure the punctuality of flight departures and arrivals.

In general, airline layover maintenance includes regular checks and short-term layover maintenance procedures, the planning of which is, in practice, separated, because their different features. Regular checks usually require 1 or more days to finish all the jobs and aircraft need to stay at the parking ramp while the tasks are performed. Short-term layover maintenance includes, a preflight check, a transit check, and a daily check. These are required before take-off and/or after landing. These checks are usually performed at the gate and take on average 1 or 2 h. Since they are performed before departure and/or after arrival, when the aircraft are at the gates, they have to fit within timetable and time constraints, otherwise punctuality would be affected incurring extra operating costs. Given the aircraft's maintenance requirements, airlines have to plan their manpower resources to perform these activities. Based on observations of Taiwan airlines, maintenance manpower demands fluctuate from time to time. The difference between peak and off-peak periods can be large. It is therefore difficult for airlines to efficiently manage their maintenance crews during fluctuation in demand.

A short-term layover maintenance plan has to consider the manpower demand, the aircraft type, the maintenance crew and the available time slots. It is almost impossible to come up with a single comprehensive maintenance plan. In general, it is practical to determine a short-term layover maintenance plan by following three steps. First, the maintenance department estimates the short-term layover maintenance manpower demand in man-hours, based on the available ground holding time slots, the different aircraft types, and the tasks required. Second, a manpower supply plan is generated according to the manpower demand obtained from the previous step. The maintenance manpower supply plan is expressed in terms of the number of work shifts and the starting time for each shift to facilitate assigning the maintenance personnel. The final step is to assign maintenance personnel to meet the supply plan but still satisfy the certificate requirements, vacation schedules, and other relevant regulations.

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2. Planning short-term layover maintenance manpower supply

Here we focus on planning short-term layover maintenance manpower supply that corresponds to the second step of the overall plan. The aim being to develop a model that can systematically and efficiently construct a manpower supply plan. There are many ways to improve manpower supply efficiency. One of these is the flexible management strategy. These strategies can increase the different degrees of freedom in the maintenance schedule. Theoretically, this can improve certain efficiency level. Therefore, we introduce several flexible management strategies that should help airlines more efficiently manage their manpower supply. This analysis fits within a longer-term development of planning in this area.

2.1. Personnel scheduling

Personnel scheduling problems can be classified into three types, according to industry characteristics: i.e. airline crew scheduling, mass transit crew scheduling, and generic crew scheduling problems (Beasley and Cao, 1996).

2.1.1. Airline crew scheduling

The generation of work shifts for cabin attendants in airline crew scheduling departments is generally divided into two stages. First, a crew scheduling problem is generated, in conjunction with the flight timetable, the official civil aviation regulations, the work conventions, and the personnel management's principles that will minimize the cost of the pairings. Second, for rostering problems, the pairings are assigned to crews that can satisfy the training, vacation, and other requirements. Langerman and Ehlers (1997) used a genetic algorithm, plus a first-in-first-out method, to solve crew scheduling problems. Yan and Chang (2002) developed a set-partitioning model and a column-generation approach for airline cockpit crew scheduling problems, while Yan et al. (2002) developed several integer programming models and column-generation-based algorithms, to minimize airline crew costs and to plan the most appropriate individual parings. Ryan (1992) formulated the airline crew rostering problem as a generalized set-partitioning model while Teodorović and Lučić (1998) developed an aircrew rostering model that could assign approximately equal workloads to all crew members. Lučić and Teodorović (1999) formulated an aircrew rostering problem as a multi-objective optimization problem, then proposed a two-step solution procedure to solve the problem.

2.1.2. Mass transit crew scheduling

Similar to airline crew scheduling practices, mass transit crew scheduling practices are generally divided into two stages, crew scheduling and crew rostering. Caprara et al. (1997) developed some crew scheduling models and algorithms that could solve both crew scheduling and crew rostering problems for a railway company. Higgins (1998) formulated the railway track maintenance crew problem as a mathematical program, then used tabu search algorithms to solve the problem.

2.1.3. Generic crew scheduling

Other than airline or mass transit crew scheduling problems, the other types are classified as generic crew scheduling problems. Beaumont (1997) formulated manpower-scheduling problems as a mixed integer program, with the objective of minimizing the manpower supply. A mathematical programming package, CPLEX, was used to solve the problem. Brusco and Jacobs (1998) developed an algorithm, by eliminating redundant columns, that could solve continuous tour scheduling problems, that are characterized by zero labor requirements in some planning periods. Brusco (1998) evaluated the performance of the dual all-integer-cutting plane for solving the generalized set-covering formulations of personnel tour scheduling problems. Alfares (1998) presented a two-phase algorithm designed to solve the cyclic manpower days-off scheduling problem.

2.2. Flexible management strategies

Flexible management strategies have become more and more popular in modern business and industries. Among the various flexible management strategies, four have recently attracted most attention and discussion: functional flexibility, numerical flexibility, temporal flexibility, and wage flexibility (Blyton and Morris, 1992).

2.2.1. Functional flexibility

Functional flexibility relates to an employer's ability to deploy and/or redeploy labor on different tasks, or to expand/contract the range of activities in which personnel are involved, according to changing organizational needs. In such a situation, staff will be required to use a wider range of skills and to demonstrate a wider range of competencies, so they can be moved from task to task. Such functional flexibility can be enhanced and/or facilitated through multi-skill training, team-based interventions, and so on.

2.2.2. Numerical flexibility

Numerical flexibility refers to the ability of employers to adjust the number of individuals working, and/or the hours worked by employees, in response to changing organizational needs. Such types of flexibility include the use of short-term or temporary contracts. Numerical flexibility is usually provided by the employment of trainee, part-time, temporary, or subcontracted workers.

2.2.3. *Temporal flexibility*

Temporal flexibility relates to variations in the number of hours worked. The relevant types of flexible work arrangements include less than full-time work, job sharing, career breaks and term-time work.

2.2.4. *Wage flexibility*

Wage flexibility, also called financial flexibility, relates to the capacity of remuneration systems to respond to different performance levels and changing labor demand/ supply situations. Within the HRM context, this type of flexibility would include performance-related-pay and special arrangements to facilitate the recruitment and retention of specialized staff in some sectors.

After reviewing the related literature, we did not find any that addressed airline maintenance manpower supply planning problems, with flexible management strategies in particular. Therefore, we focus on managing an airline's short-term layover maintenance manpower supply, with various flexible strategies, proposed based on practical concerns. We have aimed at minimizing the total maintenance manpower supply, while still satisfying the maintenance requirements and demands. The rest of the paper is organized as follows: We first describe the problem and then develop a model, which is formulated as a mixed integer program. Then, we perform a case study to demonstrate the model. Finally, we give some conclusions.

3. Problem formulation

3.1. *Problem description*

The procedure for determining a short-term layover maintenance manpower supply in this research is based on data from a leading Taiwan airline (Airline C). Airline C has three short-term layover maintenance checks, a preflight check, a transit check and a daily check. The preflight check is a regular procedure performed each time prior to airplane's take-off. It has to be finished by the scheduled departure time. The transit check is required between every two connected flights serviced by the same airplane. The daily check is executed when an aircraft stays overnight at an airport. Since the three types of checks necessitate different tasks, their working-hours and man-hour requirements are different. The tasks also vary for different aircraft types. Therefore, the manpower demand should be estimated in terms of the different aircraft types and their corresponding maintenance tasks. Airline C's minimum maintenance team is called a squad, which is currently fixed at four people, one of which is the chief. In current practice Airline C has three shifts every day, each shift having several maintenance squads on-duty.

According to Airline C's maintenance demand profile for the rotating timetable cycle, the demand fluctuates quite a lot. In some off-peak hours, there is even no demand. Therefore, flexible strategies might be a good option for Airline C to improve the efficiency of their maintenance management. Taking into consideration Airline C's practices, we proposed three flexible strategies, based on the concept of numerical and temporal flexible strategies: flexible shift, flexible squad members, and flexible working hours. The flexible shift strategy allows an employer to determine the optimal number of shifts and their starting times. They are not limited to the conventional three fixed shifts (i.e. 0:00, 8:00, and 16:00) currently adopted by Airline C. The flexible squad member strategy adjusts the number of squad members in response to changes in demand at different times. Airline C has four people in every squad. The flexible working hour strategy allows for different number of working hours. Currently, Airline C has only full-time employee. Two types of flexibility are introduced, full-time 8 h and half-time 4 h shifts.

An effective combination of shift starting times, the number of shifts, and the number of on-duty crews is important to a successful manpower supply plan. By means of the three proposed flexible strategies, we seek to provide an effective maintenance manpower supply plan that can respond to wide variations in maintenance demand.

3.2. *Model formulation*

To ensure that the model reasonably reflects reality and addresses practical concerns, we assume:

- Crew members should have the relevant certificates to maintain all the set of aircraft types. If there are many aircraft types, so that not every crew member has all the certificates to maintain all aircraft types, then the aircraft can be suitably divided into several groups according to the crew certification. Each group of aircraft can then be treated in the model. Different combinations of aircraft may be tried to find a satisfactory solution.
- The maintenance demand provided by aggregating every aircraft type in each time slot is known.
- The model only applies to a regular maintenance. Unexpected events or demands are not considered.
- Since Airline C's flight timetable is rotated weekly, 7 days is used as the planning cycle.
- The basic maintenance team is the squad. Since we are considering flexible strategies, the number of individuals in a squad can vary from 2 to 4. However,

any squad, the number of members is fixed for the period of the planning cycle.
- Full-time employees work continuously for 8 h in a shift and part-time employees work continuously for 4 h.
- For the same aircraft type, the shift starting time has to be the same every day of the week. If shift s is assigned to time J, then shift s occurs in the same time slot every day during the planning week, and has the same starting time. This assumption is made because of practical concerns. If the starting time of a shift is changed daily, it may cause confusion and would be very difficult for employees to follow.
- The shifts and their starting times are the same for a given aircraft type.
- A maintenance group consists of several squads with the same set of maintenance certificates. Therefore, a maintenance group performs the same maintenance tasks in the same time slot.
- Since the aim is to build an efficient maintenance manpower supply plan, and to focus on the planning level, we do not need to set an upper limit to the available maintenance manpower supply.
- The objective function is to minimize the total required manpower whilst satisfying the maintenance demands in each time slot. The salary structure may lead to a different solution if the objective is to minimize the operating costs. However, an objective function can be easily modified to minimize the total salary expenses for a known salary structure. Since such information is usually treated as confidential by an airline, total manpower supply is used for the objective function, without considering salary.
- The down-stream crew assignment problem is not in.

Since the planning cycle is 1 week (7 days), we let W be the set of days in a week: $W \equiv \{0$: Sunday, 1: Monday, 2: Tuesday, 3: Wednesday, 4: Thursday, 5: Friday, 6: Saturday$\}$. i denotes the ith day in a week; $i \in W$. Let N be the set of shift starting times in a day. The length of a time slot is set to be 1 h. Since there are 24 h in a day, $N \equiv \{0, 1, 2, 3, 4, 5, \ldots, 23\}$. j denotes the jth time in a day; $j \in N$. s denotes the starting time of a shift s; $s \in N$. Let P be the set of squads with different number of crews. p denotes the pth squad, $p \in P$. Let m_p be the number of crew members for the pth maintenance squad. In order to differentiate between full-time and part-time employees, we let Q be the set of different types of work, full-time jobs and part-time jobs. q denotes the qth type of work. r_q denotes the working hours for the qth type of work. Let l and u be the lower and the upper bounds, respectively, of the total number of shifts within 1 day. B is a very large number. I is the set of all integers. Let d_{ij} be the maintenance manpower demand for time slot j in day i. Let H_{ij} be the set of all shifts working in time slot j on day i. H_{ij} can be defined by Eq. (1) as follows:

Full-time job:

$$\begin{cases} \text{if} & j \in \{0, 1, \ldots, 6\}, \quad H_{ij} = \{(i', s') \mid i' = (i+6) \bmod 7, \\ & \quad 17 + j \leqslant s' \leqslant 23\} \cup \{(i', j') \mid i' = i, \quad 0 \leqslant s' \leqslant j\}, \\ \text{otherwise} & H_{ij} = \{(i, s') \mid j - 7 \leqslant s' \leqslant j\} \end{cases} \quad, \forall i \tag{1a}$$

Part-time job:

$$\begin{cases} \text{if} & j \in \{0, 1, \ldots, 6\}, \quad H_{ij} = \{(i', s') \mid i' = (i+6) \bmod 7, \\ & \quad 21 + j \leqslant s' \leqslant 23\} \cup \{(i', j') \mid i' = i, \quad 0 \leqslant s' \leqslant j\} \\ \text{otherwise} & H_{ij} = \{(i, s') \mid j - 3 \leqslant s' \leqslant j\} \end{cases} \quad, \forall i \tag{1b}$$

The decision variables are x_s and v_{ispq}. x_s is defined as follows:

$$x_s \begin{cases} = 1, & \text{time } s \text{ is a shift starting time, i.e. shift } s \text{ exists,} \\ = 0, & \text{time } s \text{ is not a shift starting time, i.e. shift } s \\ & \text{does not exist,} \end{cases}$$

v_{ispq} represents the number of required squads for the p crew member squad, for type q work, starting at shift s, on day i.

The model is developed based on the practices of Airline C. However, the framework can be easily modified to fit maintenance manpower planning problems that occur in similar airlines. The objective is to minimize the total maintenance manpower supply while satisfying the demand for every time slot. The problem is formulated as a mixed integer program:

$$\text{Min} \quad Z = \sum_{i \in W} \sum_{(i,s) \in H_{ij}} \sum_{p \in P} \sum_{q \in Q} r_q m_p v_{ispq}, \tag{2}$$

$$\text{s.t.} \quad l \leqslant \sum_{s \in N} x_s \leqslant u, \tag{3}$$

$$\sum_{s \in H_{ij}} \sum_{p \in P} \sum_{q \in Q} m_p v_{ispq} \geqslant d_{ij}, \quad \forall i \in W, \quad \forall j \in \{j \mid (i,s) \in H_{ij}\}, \tag{4}$$

$$\sum_{i \in W} \sum_{p \in P} \sum_{q \in Q} v_{ispq} \leqslant B x_s, \quad \forall s \in N, \tag{5}$$

$$x_s = 0 \text{ or } 1, \quad \forall s \in N, \tag{6}$$

$$v_{ispq} \geqslant 0 \quad \text{and} \quad v_{ispq} \in I, \quad \forall i \in W, \quad \forall s \in N, \quad \forall p \in P, \quad \forall q \in Q. \tag{7}$$

Eq. (2) minimizes the total number of man-hours. Eq. (3) constrains the number of shifts within a given range. Eq. (4) states that the assigned crew members have to at least meet the maintenance demands in every time slot. Eq. (5) indicates that the maintenance unit is assigned to a shift only when the shift exists. Eqs. (6) and (7) show the integer and non-negativity constraints on variables.

We use an example to demonstrate the problem size of the model. Consider a 7-day timetable with 24 possible shift starting times in 1 day, three different crew member numbers and two types of work shifts—full-time and part-time. There are 24 different x_s s and 1008 $(7 \times 24 \times 3 \times 2)$ v_{ispq} s. There will be two constraints corresponding to Eq. (3), 168 (7×24) corresponding to Eq. (4) and 24 corresponding to Eq. (5). In total, there will be 1032 integer variables and 194 constraints.

4. Case study

Airline C's short-term layover schedule and maintenance demand is used, from June 5, 2000 to June 11, 2000, as test data. They use six different types of aircraft, 51 in total. The corresponding maintenance demands, with respect to each type of aircraft, are summarized in Table 1. Assuming that crew members can maintain all these aircraft types, we sum all the demands associated with each aircraft type, to find aggregated maintenance demand.

Fig. 1 illustrates the maintenance demand in man-hours per day. The largest maintenance demand appears from 20:00 to 23:00. The other peaks are 6:00–8:00, 11:00–13:00, and 15:00–16:00.

The solution procedure was developed using CPLEX coupled with C programs. In preliminary tests, the finding of an optimal solution took a lot of computational effort. In a trade-off between computational efficiency and solution accuracy, we cut off the solution procedure after over 600 s of CPU time, after which the solutions rarely improved. The current number of shifts for Airline C is 3. Therefore, the shift upper bound (u in the model) was from 3 to 6 (Table 2). A larger number of shifts indicate more manpower flexibility and more feasible combinations. A better objective value, total manpower supply in man-hours, can, therefore, be obtained.

Table 1
Maintenance demand for each aircraft type

Aircraft type	Abbreviation	Number	Maintenance demand[a]
Airbus A300-600R	Ab6	12	1577
Boeing 737-800	B738	10	2388
Boeing 747-200	B742	1	226
Boeing 747-200F	B742f	11	558
Boeing 747-400	B744	13	1218
Md-11	Md11	4	265
Summary	—	51	6232

[a] The demand has been converted to man-hours/week.

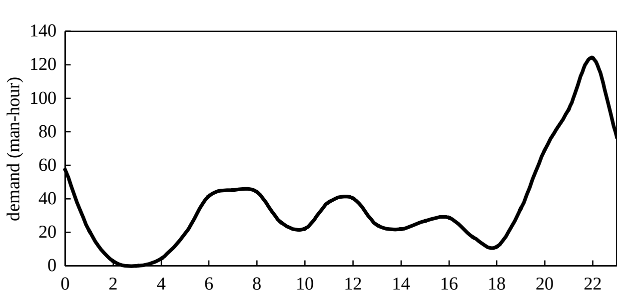

Fig. 1. Maintenance demand profile.

One observation from the table is that the best shift starting times match the maintenance demand curve (Fig. 2). For example, the maintenance demand peaks between 20:00 and 22:00. If there are six shifts, the best shift starting times will be 5:00, 13:00, 19:00, 20:00, 21:00 and 22:00, which has the same trend as the demand profile. This implies that if there are apparent peaks in the maintenance demand profile, a flexible shift strategy is the approach for improving the efficiency of human resource management.

The full-time and half-time manpower supply associated with the number of shifts can be analyzed as shown in Table 2. The comparison between full-time and half-time supply is illustrated in Fig. 2. As the number of shifts increases, the number of half-time personnel increases, while the number of full-time personnel decreases. Since increasing the number of half-time maintenance personnel would increase the manpower supply flexibility, total man-hours decreases and a better solution is obtained. This also implies that, for a larger number of shifts, the system requires more flexibility in arranging its personnel and a higher percentage of half-time employees would more effectively meet the requirements.

The model implies that the unit man-hour payments for full-time and half-time personnel are the same. However, it is likely, that the salary structure for full-time and half-time manpower differ. To incorporate the influence of full-time/half-time manpower hourly payments, the half-time/full-time payment ratio is defined as the half-time hourly payment divided by the full-time hourly payment. The half-time/full-time payment ratios are varied from 0 to 3 given the same input data. The best combinations of shift schedules, squad size, and number of full-time/half-time employees, with different payment ratios can be found. The total salary expenses for every case is calculated to evaluate the influence of half-time/full-time salary structures—Figs. 3 and 4. As the relative half-time salary increases, the total salary expense increases. In particular, when the half-time/full-time payment ratio goes up to 2.5, the use of half-time employees does not give any advantage in reducing the overall manpower arrangement. The 100% full-time employees is thus a better choice. Moreover, total salary expenses do not increase after the payment ratio is more than 2.5, because all the employees are then full-time and the salary is fixed for full-time employees. This

Table 2
Results for changing the upper bound of the shifts

Upper bound of the shifts	Optimal number of shifts	Total manpower supply per week (man-hours)	Best shift starting times	Total manpower per week (persons)		Computation time (s)
				Full-time	Half-time	
3	3	9956	4, 12, 20	978	533	600.062
4	4	8044	5, 13, 19, 21	570	871	600.094
5	5	7724	5, 13, 19, 21, 22	484	963	429.797
6	6	7672	5, 13, 19, 20, 21, 22	463	992	600.141

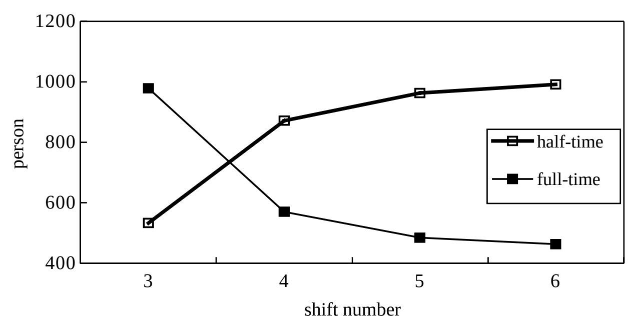

Fig. 2. Comparison of full-time/half-time manpower.

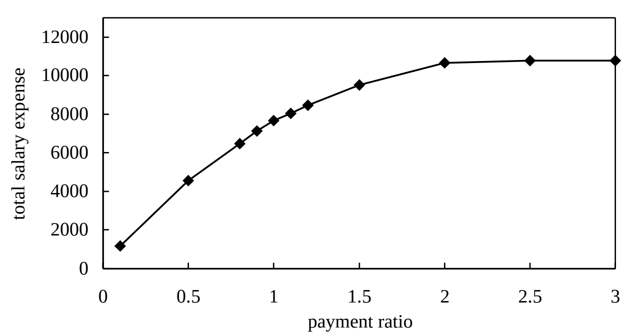

Fig. 3. Total salary expenses under different half-time/full-time payment ratios.

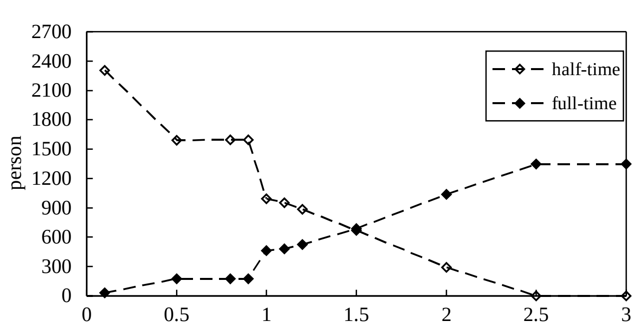

Fig. 4. Full-time versus half-time manpower under different half-time/full-time payment ratios.

Table 3
Squad members versus total maintenance crew

Members in squad	2	3	4	5	6
Total manpower supply (persons)	1600	1611	1624	1625	1632

implies that, although half-time employment is an effective strategy for manpower supply management, as the relative half-time payment increases so the effectiveness of the half-time employment strategy decreases.

The flexible squad member strategy is also tested. To isolate the influence of a flexible squad member strategy, the tests used Airline C's current maintenance management strategy. This has three fixed shifts per day, 8 working-hours per shift, and predetermined shift starting times at 0:00, 8:00, and 16:00. The number of squad members was varied between 2 and 6. The results are summarized in Table 3, for 1 week of manpower supply versus the corresponding number of squad members. As the squad size increases, the total manpower number per week increases. This implies that a smaller squad size could provide more flexibility in manpower supply planning. However, marginal increases in the total maintenance manpower supply are not uniform. For example, irrespective of whether there are 4 or 5 squad members, there is almost the same total manpower supply.

5. Conclusions

One of the challenges for an airline maintenance department is to set up a good maintenance schedule for both crew members and aircraft that will ensure flight safety and flight punctuality. A good maintenance manpower plan can significantly reduce operating costs. Recently, flexible management strategies have become popular and have been applied to some industrial organizations. However, the concept has seldom been formulated as a systematic mathematical model. Based on the concept of numerical and temporal flexibility, we incorporated three different flexible strategies, in particular flexible shifts, flexible squad members, and flexible working hours, to develop a model that will solve for an effective maintenance manpower supply plan. The model was formulated as a mixed integer program, with still the objective of minimizing the total maintenance manpower supply, while satisfying all the requirements and the demands in each time slot.

From the preliminary test results, such flexible strategies have proven efficient in terms of manpower arrangement. This indicates a new direction for maintenance departments to more efficiently arrange their manpower and schedule their maintenance crews. Finally, we assume that crew-members could maintain all aircraft types, which implies that the maintenance schedule does not have to consider different types of aircrafts. The manpower plan problem becomes more complex if multiple aircraft type maintenance manpower requirements are included.

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